Review of the paper by Obeyskera et al. dated 6/4/06
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June 30, 2006

Introduction

The purpose of this paper is to present my review of the draft paper by Obeysekera et al. dated 6/4/06 and titled *Consideration of Long-Term Climatic Variation in SFWMD Planning and Operations.* While the title of the paper suggests a focus on long-term climatic variation, the paper discusses possible variations at several scales from a few days to decades. It would be helpful to define more explicitly the types of trends that are being evaluated. The other key definitional term is whether the analysis focuses on trends in central tendencies that argue that the long-term averages are changing, or focuses on trends in extreme events, e.g., peak rainfalls are increasing. The paper discusses all of these topics in varying degrees of detail.

The review follows the format suggested by the SFWMD.

1. Has the District adequately addressed the long-term wet and dry cycles in modeling for a) facility planning, and b) operational planning? If not, what standard engineering practices can the District modelers follow to address climate variability due to indicators such as AMO?

Response:

The District uses the 36 year daily period from 1965 to 2000 as its official design condition for the South Florida Water Management Model (SFWMM). Much of the paper is devoted to evaluating whether this period provides a representative sample of expected future climatic events and their variability. They conclude on p. A-iii that "…the historical period provides appropriate and reasonable estimates of the ranges of climatic conditions that are likely to be experienced in coming years."

a) For **facility planning** in the District, the concern is usually based on design events for the individual purposes of water supply, flood control, and water quality control. In engineering design, the performance is typically measured based on a design event or the integrated performance over a specified time period, e.g., average load reduction during the 36 year simulation period. A brief discussion of project design for flood control and water supply is presented on page 22. What is missing is an analysis regarding the statistical nature of extreme flood and drought events within the 36 year simulation period. The authors mention the 100 year storm and standard project storm for flood control. No mention is made of design events for water supply but these are typically specified based on the criticality of the water supply needs. It should be straightforward to add these analyses so that the reader can have a better sense of the variability that is contained in the selected 36 year period.

For flood control, the 36 year period could be a good selection if it contained some extreme events including major hurricanes. Three 2004 hurricanes (Charley, Frances, and Jeanne) passed over the Kissimmee Basin. However, there were relatively few hurricanes in South Florida during the last half of the 20th century. In standard engineering practice, the design of a specific facility is governed by accepted guidelines for the structural integrity of the facility itself, e.g., the levee will not fail even during the standard project flood. The design also specified a level of service for flood control, e.g., one in 50 year flood protection for downstream areas. These conditions must be met for each facility. The use of the 36 year daily record and the SFWMM is problematic in this case since it is a complex regional model and can't be easily used to evaluate individual projects under specific design conditions. Thus, other more detailed models are used to design individual projects. These detailed models use boundary conditions from the SFWMM and then do much more detailed, site specific, analyses. Another limitation with the 36 year period for design is that a performance metric needs to be specified that is compatible with accepted engineering design standards. However, I don't think that the District has such metrics. For example, is the design of the EAASR project acceptable if it never discharges flows that exceed a certain rate during the 36 year period?

Safety factors are associated with standard engineering design to reflect our uncertainty regarding future conditions. While traditionally, the safety factors related to our uncertainty regarding natural disasters, anthropogenic causes are now included to reflect the post-911 world. The inclusion of safety factors is an important point to make regarding the potential threat of climate change. Safety factors are applied to all elements of the design and reflect uncertainty regarding all aspects of the design including projected future demands, climate, design, construction, and/or operations problems, terrorist attacks, changes in priorities, etc. Thus, it is the relative risks of each of these sources of uncertainty that needs to be determined. In this context, the uncertainty regarding long-term climate change may not be significant relative to uncertainty about the types of hurricanes that we might experience during the life of the project.

On the water supply side, Williams et al. (2006) Kissimmee River Restoration and Upper Basin Initiatives. Chapter 11 in 2006 South Florida Environment Report.
http://www.sfwmd.gov/sfer/SFER_2006/volume1/chapters/v1_ch_11.pdf
discuss water supply planning. They cite a goal of providing options for a 1-in-10 year level of certainty for all reasonable beneficial uses of water. They also note that water demand in the Kissimmee River Basin is expected to increase from 262 mgd in 2000 to 432 mgd in 2025. The *Kissimmee Basin Water Supply Plan, 2002.* http://www.sfwmd.gov/org/wsd/wsp/kisswsp.htm discusses water supply issues and plans in more detail. Because a large part of the water supply of South Florida comes from groundwater sources, it is less vulnerable to shorter term droughts than areas that depend primarily on surface water sources. It would help if the report described the extent of droughts during the 36 year period and their severity. Design standards for water supply are more flexible than for flood control since droughts occur over longer time horizons than floods and people have time to adapt, e.g., restricting outdoor water use. Nevertheless, it is still standard engineering practice to specify a level of service to be provided by an individual project or collection of projects.

In summary, using a 36 year daily simulation period and the SFWMM for project and system design is atypical for standard engineering practice. The discussion should include accepted design criteria for water supply, flood control, and water quality control. Then, a comparison can be made as to how representative the 36 year period is in terms of these design conditions, e.g., does it include a 100 year storm event? Also, it is still problematic to use the boundary conditions from the SFWMM to design a specific project within the District because of the need to jointly use the 36 year flow trace and a specified design condition, e.g., the 100 year, 24 hour duration storm at a particular location.

I would hypothesize that the projected climate changes are relatively unimportant compared to the other sources of uncertainty and could be ameliorated by adaptive management of the operations over time. The paper should point out these other sources of uncertainty and that climate change, terrorists' acts, and levee failure mode lessons from Hurricane Katrina are the most recent additional criteria that engineers need to incorporate into their design decisions. This process always has used adaptive control (management) to refine designs. I developed Table 1 from work by Yevjevich (1986) that lists a variety of sources of risks and uncertainties in water projects. Climate variability needs to be added to this list.

Table 1. Types and sources of risk and uncertainty in water resources.
Adapted from Yevjevich, V. (1986).

Technological	**Socio-Economic**	**Human Performance**
Structural integrity	Water demand	Fatal errors
Compatibility of components	Benefit over-estimation	Human flaws
Fatal flaws in components	Cost under-estimation	Sabotage
Fatal flaws in technology	Public rejection	Rebellion, war
Underdesign	Political entanglements	Institutional flaws
Flaws in automation	Environmental errors	
Deterioration of materials	Legal compli-cations	
General aging	Financial mistakes	

Reference:
Yevjevich, Y. (1986) The risk factor in water resources. In Haimes, Y.Y. and E.Z. Stakhiv, Eds., Risk-Based Decision Making in Water Resources, ASCE, New York, p. 129-140.

b) For **operations planning,** the authors present a nice analysis beginning on page 22. The discussion beginning on page 24 about the WSE schedule and associated forecasting is good. This operations forecasting includes two week forecasts as well as longer term forecasts. The multi-objective tradeoff analysis, summarized in Figure 12, p. 25, is very nice.

A significant part of the paper (p. 11 to 16) discusses rainfall-runoff relationships in the Kissimmee River Basin, the largest source of water for Lake Okeechobee. Four cool and warm periods as defined by AMO were identified and the most recent three periods (AMO 2-warm, 1926-1969; AMO-3, cool, 1970-1994; and AMO (warm), 1995-2005) were evaluated in more detail. If Figure 1 in the paper is used, then the third “cool” period begins about 1967, not 1970. If these added years are included, then the average annual rainfall during this cool period will increase since 1969 and 1970 were very wet years. In this context, warm and cool refer to surface ocean temperatures in the North Atlantic Ocean. The annual precipitation from 1895 to 2005 is shown in Figure 3, p. 8. The first question for this reviewer is whether there is a statistical relationship between annual average ocean temperature and annual rainfall. The data presented in Figure 3 show that the mean rainfall is lower in the cool years than it is in the warm years but the differences are not large and are well within one standard deviation of the mean rainfall. The more important question for operations planning is whether a meaningful transfer function exists between ocean temperature and future climate in South Florida. For response times on the order of a few days or weeks, meteorologists can use this information for forecasting future weather. However, as the forecasting period extends to months or years, the reliability of the forecasts decreases. The authors present analysis in Appendix A that suggests that the AMO can impact monthly distributions of precipitation. I agree with the authors’ conclusions that the cause-effect linkage between ocean surface temperatures and annual or monthly rainfall is not strong enough to warrant changing their currently used rainfall distributions.

The discussion on predicting climate/hydrologic outlooks for South Florida (p. 11) summarizes earlier efforts at SFWMD to more fully incorporate ENSO and other indices into their operations planning. They cite the NOAA Climate Prediction Center that provides predictions of precipitation and temperature and include one and three-month forecasts. They also cite a recent conference paper by Trimble et al. (2006) that summarizes how they have applied climate outlook methods. This section would be more valuable if the authors tell us what the District actually does use as opposed to what they could use to make these forecasts. It appears that the District is already using state of the art techniques for forecasting future weather and adjusting their operations accordingly.

Lake Okeechobee Net Inflows-P. 11
The authors present an evaluation of how representative the 1965-2000 period is in terms of annual net inflow to Lake Okeechobee using data from the 1914-2005 period. Their Figure 5 shows the cumulative density function of annual inflows. This figure seems to indicate that the 1965-2000 inflows provide a good cross section of the larger data set. They plot annual rainfall-runoff data for the Upper Kissimmee River Basin (S 65) and the total Kissimmee River Basin (S 65E) for 1926 to 2005 for AMO2, AMO3, and AMO4 periods. They conclude that it is difficult to see a difference in the rainfall-runoff relationships for the three AMO periods. The authors state that other factors such as regulation of the lakes in the Upper Kissimmee Basin and land use and structural changes in the Lower Kissimmee River Basin may be responsible for any changes in the rainfall-runoff relationships.

The Kissimmee River Basin has undergone major changes between 1914 and the present. Bedient, Huber, and Heaney (1977) summarize the results of the application of an environmental model of the Kissimmee River Basin (KRB). This model divided the KRB into 18 watersheds. A detailed land use analysis was performed for the study area. The combined impacts of major land drainage throughout the KRB, the construction of regulating reservoirs in the Upper KRB, and the channelization of the Lower KRB produced a dramatic impact on both water quantity and quality. Prior to development, the KRB responded very slowly to the wet season as shown in the rainfall-runoff relationships for 1943-54 and 1960-61 where the recession occurs over several months. However, after the development of the KRB, the hydrograph response was much quicker as shown in the flow data for 1969-1970. This Figure 3 is from Bedient et al. (1977).

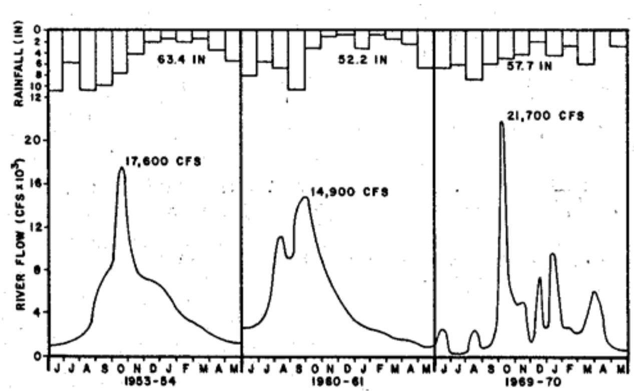

FIG. 3.—Flood Hydrographs for Kissimmee River near Okeechobee, Fla.

Bedient et al. (1977) concluded that:
1. Land use has changed significantly between 1958 and 1972 with transition from a marsh/swamp drainage system to a regime dominated by improved pasture and lateral drainage canals.

2. Detention times have decreased due to increased drainage activities, and the basin hydrologic response appears to be more sensitive to effects of upland drainage rather than just the condition of the narrow river flood plain.
3. Excessive drainage activities have led to greater surface runoff volumes and nutrient loads in the river basin, and the greatest potential for control of runoff quantity and quality exists through on-site storage in marsh, pond, and lake areas.

Ref.
Bedient, P.B., Huber, W.C., and Heaney, J.P. 1977. Environmental model of the Kissimmee River Basin. *Jour. of Water Resources Planning and Management*, Proc. ASCE, 103 (WR2): 241-256.

Others have also looked at the effects of development on the hydrology of the KRB. I was not able to find a copy of the following report by Obeysekera and Loftin that provides a more recent evaluation.

Ref.
Obeysekera, J., and K. Loftin, 1990. Hydrology of the Kissimmee River Basin. Influence of Man-Made and Natural Changes," Kissimmee River Restoration, Alternative Plan Evaluation & Preliminary Design Report, South Florida Water Management District, June.

This discussion regarding the rainfall-runoff relationship for the KRB vividly illustrates the need to look simultaneously at all significant sources of uncertainty so that the **relative** importance of each source can be determined as discussed earlier. I suspect that the District has already done this type of analysis. If so, then it can be cited in this paper.

2. Does the modeling approach used by the District for both CERP and WSE schedule design meet the requirements of standard engineering and design practices? If not, what additional steps should the District take to improve modeling for these applied purposes?

Response:
As mentioned in the response to question 1, the major gap is lack of a statement regarding the probabilities of the extreme events that are contained in the 36 year simulation period. In the post-Katrina world, the general public knows what a category 3 hurricane is and that the levees in New Orleans were not designed to protect high valued urban areas.

The 36 year daily simulation provides a nice integration of what happens overall. It needs to be supplemented with design event simulations for extreme events to address current questions such as the adequacy of the Lake Okeechobee levees. The paper talks about how designs are based on a benefit-cost-risk (BCR) analysis. However, this is not the norm in current engineering analysis. Few water design standards explicitly use BCR analysis. The Corps still does benefit-cost analysis for flood control and water supply but not for environmental analysis. I am not aware that the District uses any sort of formal BCR analysis. While I personally subscribe to the concepts of BCR analysis, it remains controversial especially the risk analysis portion because your explicitly and publicly admit that there is a probability of failure. See the 2000 NRC report on this subject.

Ref.

National Research Council (2000) Risk Analysis and Uncertainty in Flood Damage Reduction Studies. Commission on Geosciences, Environment and Resources, Washington, D.C.
http://darwin.nap.edu/books/0309071364/html/12.html

The District's modeling approach for both CERP and WSE schedule design is atypical. The SFWMM is run for the entire region and provides estimates of the expected impact of one or many projects. A basic question in CERP is when a particular project is brought online, e.g., is first or last? This can have a major impact on how it performs. In this paper, only the SFWMM is described. A brief discussion is needed of how the regional model is used along with more detailed, project specific, simulators to design a project that is compatible with regional, as well as project specific, goals.

3. Are the steps being taken in the adaptive management/modeling approach used by the District adequate to address the uncertainties in climate prediction and to assimilate new information?

Response:

The paper devotes only one paragraph on p. 28 to adaptive management. The District has widely publicized how it has been and will continue to use adaptive management to refine the operations of the system as needed. It is important to inform the reader that it is not easy to make changes in operations on this complex project since virtually any change in operations causes both benefits and costs to a wide variety of stakeholders who would tend to resist such changes. Traditionally, the Corps' operating rules have tended to be relatively inflexible and codified in rigid operating rules, e.g., the Lake Okeechobee rule curve shown in Appendix B of the paper. One of the major challenges of CERP is to determine what the new operating rules will be with some or all of the projects online. This question is not yet resolved.

4. Except for basic research approaches, are there other facility planning options that the District should consider to address the possibility of a continued wetter cycle?

Response:

I am assuming that facility planning is synonymous with the facility sizing decision as opposed to the operations planning. In this context, it is not clear what levels of service are being specified for design criteria for water supply and flood control. Environmental restoration is being driven by a total phosphorus standard of 10 ppb. Examples of design criteria for water supply and flood control are shown below:

A. Water supply

- Agriculture and outdoor urban water use-provide full supply in 90% of the years
- Indoor urban water use-provide full supply in 99% of the years.

B. Flood control

- Agriculture-protection up to the ten year flood level
- Urban-protection up to the 100 year flood level

Given some probabilistic statement regarding the level of service, the question of climate changes can be couched in terms of potential changes in these levels of service. For example, if climate change is felt to exacerbate extreme floods, then an argument could be made that the one in 100 year flood may soon be a one in 50 year flood. Thus, 100 year flood delineations would need to be revised.

Without a clear statement regarding current and projected levels of service, it is hard to talk about the potential impacts of climate changes.

I suggest that the District prepare a document that illustrates how all sources of uncertainty are incorporated into design and operation. This document should include a determination of the relative risks of each of the key unknowns in the design and operation and how safety factors have been used to provide assurances of acceptable operation even for such complex systems. It is difficult, if not impossible, to do this analysis using the SFWMM, because it is too complex and run times are prohibitively long. My favorite approach is to do Monte Carlo simulation on a much simpler spreadsheet model that incorporates the major sources of uncertainty as illustrated in Table 1 of this review. Using risk analysis software such as @Risk or Crystal Ball, it is easy to generate thousands of outcomes and then determine the relative importance of each one as it affects the final design. Relative importance is determined by an analysis of variance of the input factors and the final results are displayed as a tornado plot of correlation coefficients or normalized regression coefficients. This method is a valuable aid in determining the **relative** importance of each source of uncertainty relative to a specified project outcome, e.g., project cost. This analysis would provide a balanced view of the expected relative importance of climate change as compared to the many other sources of uncertainty in water resources design and operation.

5. Are the data and models used by the District appropriate (reasonable and adequate) for their intended applications?

Response:

The SFWMM is a valuable tool for evaluating the design and operation of the increasingly complex SDWMD system. Its daily time step allows it to characterize the dynamics of individual events like large rainfalls. Its spatial disaggregation and inclusion of the vital operating rules provide a fairly realistic representation of the flows of water through the system. It needs to be supplemented with more detailed process models that provide a more realistic evaluation of the expected performance of individual projects within the system under accepted engineering design conditions such as the 100 year flood.

The focus of the paper is on the potential impact of climate change on the design and operation of District facilities. As mentioned earlier, forecasting the future conditions across all aspects of system design is a very challenging issue and climate uncertainty is only one of many sources of this uncertainty.

The paper should stress that the District already uses sophisticated methods to incorporate the latest technologies in climate forecasting to project future scenarios and adjust operations accordingly. What simulation models does the District use for short-term (one week to a few months) forecasting and how often are these projections updated? While the District uses the phrase *adaptive management*, I prefer to use the engineering term of *adaptive control.* Control theory is a highly developed technique in engineering for guiding the operation of everything from airplanes to water treatment plants. Operations can be modified at time scales ranging from micro seconds to months depending on the system that is being managed. It would be instructive to inform the reader regarding how these adaptive control decisions are being made by the District. Major breakthroughs in sensors and data management have greatly improved our ability to do adaptive control of complex systems.

List any issues/concerns which you feel MUST be addressed before this document can be published

Response:

Overall, the paper is well prepared and presents a variety of useful information. I have suggested several possible changes and refinements in the review. Ultimately, the paper is written for an intended audience. It is not clear to me who this intended audience is. Given the wide interest in “An Inconvenient Truth”, one audience would be District customers who are concerned that climate change may affect them. The graphic in the movie showing the rising sea levels and their effects on south Florida is a dramatic example. Also, the linkage of global warming with hurricanes like Katrina in this movie is cause for concern among many citizens. The current document provides some solace to people in south Florida that the District has been studying this problem and has incorporated some of the predictive techniques into its operations and planning. If the paper or a condensed version of it is to be submitted to a peer-reviewed journal, then it needs to focus on a particular methodological issue. If the report is to be in the form of a general technical report of the District, then it probably OK as is with some minor editing.

Please list areas of the publications that were NOT covered by your review

Response:

I am not a meteorologist. Thus, I did not comment on the pros and cons of the various forecasting methods that are described in the paper.

Please list any typos or minor format issues that must be covered

Response:

A. Specific editorial suggestions.

1. P.1 ,par. 3, line 13. **is** should be **this.**
2. P. 6, Fig. 1 ordinate. Define temp. anomaly.
3. P. 7, Fig. 2. Define SST anomaly and AMO index in text.
4. P. 10, Fig. 4a. Define PDO index.
5. P. 10, Fig. 4 title. Missing adjective in front of correlation on second to last line.
6. P. 11, par. 1 is a repeat of what you said on p. 6.
7. P. 12, Fig. 5. Ordinate units need to be explained. Now reads as feet over 467,000 acres. It should be a flow rate. What is the significance of 467,000? The two shades of red in the bar graph are hard to distinguish.
8. P. 14, Fig. 6. One data point is labeled 34-36. Should only be one year.
9. P.14, Figure 7. Title is wrong. It should be Rainfall-runoff relationship for the Upper Kissimmee River Basin above S 65 as shown on page A-8.
10. P. 15. Title on Fig. 8 is wrong.
11. P. 16, Fig. 9. Figures are too small and hard to read.
12. P. 11-16. This section on inflows to Lake Okeechobee needs to present a more balanced analysis of other reasons why runoff might differ during these two periods. E.g., installation of control structures, intensified land use and drainage.
13. P. 13, lines 5 and 7. cold should be cool. Several places in the report, cold and cool are used interchangeably. I'd suggest using cool as in warm and cool instead of cold as in cold and hot.
14. P. 17 et seq. Discussion on modeling focuses on the 2x2 model. Need to show the areas that are covered by the 2x2 model and that it does not include the areas north of Lake Okeechobee that are the subject of the rainfall-runoff analysis. Checking the ongoing work in the Kissimmee River Basin indicates that a basin model is being developed now but none was available to support the work described in this paper. It would help to briefly explain how these inflows from the north of Lake Okeechobee are estimated.
15. P. 18, Section on variability in simulation period. It would be helpful to cite how the 36 year period ranks in terms of extreme events during this period, e.g., how many hurricanes and extended droughts occurred.
16. P. 20, last line. Reference is too vague.
17. P. 22, Operations section, line 4. Trimble (2005) reference is missing.
18. P. 28, line 2. "…during 1962 within the 1965-2000 planning period". Meaning?
19. P. 31 et seq., References need to be better organized as follows:
    - **a.** Be consistent in abbreviating first names.
    - **b.** Organize Trimble references chronologically
    - **c.** Tasker reference needs volume and issue numbers.

20. P. B-1. Appendix B is very hard to read.

B. General Editorial Suggestions

Many of the key citations to work done by SFWMD personnel that are vital background material for this report are from conference proceedings that are not accessible. It would be helpful to have pdf files of them available so readers can review them.